TITLE OF THE INVENTION

DESIGN VARIABLE OPTIMIZATION SYSTEM AND DESIGN
VARIABLE OPTIMIZATION METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a design
variable optimization system and a design variable
optimization method for determining a specific design
variable from among numerous design variables according
to a particular evaluation criterion, for a design
article whose performance varies with change of the
design variable.

Related Background Art

There are well-known design variable optimization
systems for determining a specific design variable from
among numerous design variables according to a
particular evaluation criterion, for a design article
whose performance varies with change of the design
variable. Such design variable optimization systems
normally include a performance value calculating
section for carrying out an analysis (simulation) on a
design article for a fixed time using each of the
design variables and for calculating a performance
value for evaluating the performance of the design
article using each of the design variables, based on
the result of the analysis. Known systems also include

1

a design variable determining section for applying each of the performance values calculated by the performance value calculating section, to the foregoing evaluation criterion, thereby determining an optimal design variable from among the numerous available design variables.

For example, let us consider designing an article such as a pillar of a car. The pillar of a car is a design article whose so-called "upper interior head impact protection requirements" varies according to several design variables, e.g., the thickness of ribs located on the pillar, the thickness of the outer wall of the pillar, and the interval between the ribs of the pillar. Namely, when the pillar is designed in a design variable optimization system, the aforementioned performance value calculating section first calculates by simulation a dynamic change of acceleration within a fixed time during a collision of an object (e.g., Free Motion Headform) with the pillar using a combination of each of the design variables, i.e., variously changed values of the thickness of the ribs on the pillar, the outer wall thickness of the pillar, and the intervals between ribs on the pillar. The performance value calculating section further calculates an HIC(d) as a performance value for evaluating the upper interior head impact protection requirements of the pillar of

the car, using a calculated dynamic change of acceleration. The design variable determining section then compares the various HIC(d) calculated by the performance value calculating section, and determines a combination of rib thickness on the pillar, outer wall thickness of the pillar, and rib interval on the pillar that provides a minimum HIC(d), thus achieving an optimal design for the pillar.

SUMMARY OF THE INVENTION

However, known design variable optimization systems are disadvantageous. Namely, known design variable optimization systems carry out analysis on each design variable of the design article for an equal and fixed amount of time, regardless of whether or not such as necessary, in order to calculate each of the performance values for evaluating the performance of the design article. However, the result of the analysis on the design article often differs depending upon each of the design variables, so that the analysis time necessary for the above calculation of a performance value often differs depending upon each design variable. As a consequence, if the analysis on the design article is carried out in the known manner described above, analysis on the design article will be conducted even when not necessary for the calculation of a performance value, thus requiring a long time for the determination

of a design variable.

The present invention has been accomplished to, among other things, avoid the above discussed disadvantages of known systems. Thus an object of the invention is to provide a design variable optimization system and a design variable optimization method capable of determining a design variable within a short time.

For accomplishing the above object, and other objects, a design variable optimization system is provided according to the present invention whereby a specific design variable is determined from among numerous design variables according to a certain evaluation criterion, for a design article whose performance varies with change of the design variable. The system in accordance with the present invention includes performance value calculating means for performing an analysis on the design article using the design variables and for calculating a performance value for evaluating the performance of the design article using each of the design variables, based on the result of the analysis. A design variable determining means is also provided for determining the specific design variable among the design variables, based on each of the performance values calculated by the performance value calculating means and the

4

evaluation criterion. An analysis end time determining

means is provided for determining an end time of the

analysis in the performance value calculating means so

that a prescribed relation is satisfied by an end time

5   of a period necessary for the calculation of the

performance value and the end time of the analysis.

For also accomplishing the above object, and

other objects, a design variable optimization method is

provided according to the present invention whereby a

10   specific design variable is determined from among

numerous design variables according to a certain

evaluation criterion, for a design article whose

performance varies with change of the design variable.

The method in accordance with the present invention

15   includes a performance value calculating step of

performing an analysis on the design article using each

of the design variables and calculating a performance

value for evaluating the performance of the design

article. The method also includes a design variable

20   determining step of determining the specific design

variable from among all of the design variables, based

on each of performance values calculated in the

performance value calculating step using an evaluation

criterion. The method also includes an analysis end

25   time determining step of determining an end time of the

analysis in the performance value calculating step so

that a prescribed relation is satisfied by an end time
of a period necessary for the calculation of the
performance value and the end time of the analysis.

Since the end time of the analysis is determined
so that the prescribed relation is satisfied by the end
time of the period necessary for the calculation of the
performance value and the end time of the analysis,
protracted and unnecessary analysis is avoided during
the calculation of the performance value, and thus the
analysis can be carried out efficiently. As a result,
the design variable can be determined within a short
time.

The present invention will be more fully
understood from the detailed description given
hereinbelow and the accompanying drawings, which are
given by way of illustration only and are not to be
considered as limiting the scope of the present
invention.

Additionally, further scope of applicability of
the present invention beyond that of the particular
embodiments discussed herein will be apparent to one
skilled in the art from the detailed description given
hereinafter. Therefore, it should be understood that
the detailed description and specific examples, while
indicating preferred embodiments of the invention, are
given by way of illustration only, since various

changes and modifications within the spirit and scope
of the invention will be apparent to those skilled in
the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

5   Fig. 1 is a block diagram of a design variable
optimization system in accordance with the present
invention;

Fig. 2 is a diagram showing a dynamic change of
acceleration a(t);

10   Fig. 3A to Fig. 3C are diagrams showing
determination procedures of analysis end time t_e;

Fig. 4 is a flowchart showing the operation of
the design variable optimization system; and

Fig. 5 is a block diagram of another design
15 variable optimization system in accordance with the
present invention.

Fig. 6 is a perspective view of a pillar.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Design variable optimization systems according to
20 the present invention will be described with reference
to the drawings. First, the structure of a design
variable optimization system according to the present
embodiment will be described. Fig. 1 is a block
diagram of a design variable optimization system in
25 accordance with the present invention.

The design variable optimization system 10

according to the present embodiment is generally a design variable optimization system for determining a specific design variable from among numerous design variables according to a certain evaluation criterion, for a design article that varies its performance with change of design variable. More specifically, it is, for example, a design variable optimization system for determining the optimal rib thickness of a pillar, outer wall thickness of the pillar, and rib interval of the pillar (specific design variable) presenting the minimum HIC(d) (certain evaluation criterion), which is a valuation of the upper interior head impact protection requirements, for the pillar (design article) of a car that varies the upper interior head impact protection requirements (performance) with change in the rib thickness of the pillar, the outer wall thickness of the pillar, and the rib interval of the pillar (design variable).

Pillar is one of the energy absorbing parts of car, which is described in Fig.6. Pillar 100 is mainly constructed of ribs 102 and outer walls 104.

The design variable optimization system 10 of the present invention in one embodiment is composed, as shown in Fig. 1, of a performance value calculating section 12, a design variable determining section 14, and an analysis end time determining section 16. Each

of the components will be described below in detail.

The performance value calculating section 12 performs the analysis on the design article using each of the design variables and calculates a performance value for evaluating the performance of the design article, based on the result of the analysis. Here the analysis on the design article, carried out by the performance value calculating section 12, is a simulation concerning dynamic behavior of the design article.

More specifically, the performance value calculating section 12 performs the analysis on the pillar of a car based upon combinations of a variety of rib thicknesses of the pillar, outer wall thicknesses of the pillar, and rib intervals of the pillar, and calculates the HIC(d), which is a performance value for evaluating the performance of the pillar of the car.

Namely, the performance value calculating section 12 first calculates the acceleration a(t) of Free Motion Headform at time t when Free Motion Headform collides with a pillar of car having a particular combination of rib thickness of the pillar, outer wall thickness of the pillar, and rib interval of the pillar, all set by the design variable determining section 14. The acceleration a(t) is calculated by numerically solving a modeled collision phenomenon between the

pillar of a car and Free Motion Headform using a differential equation (simulation), and it changes with time, for example, as shown in Fig. 2. Here the performance value calculating section 12 continues the calculation of acceleration a(t), particularly, up to an analysis end time t_e determined by the analysis end time determining section 16 (the details of which will be described hereinafter).

In addition to the calculation of acceleration a(t), the performance value calculating section 12 also calculates a valuation $f(t_1, t_2)$ represented by Eq (1) below, in a time domain where the acceleration a(t) has already been calculated. The valuation $f(t_1, t_2)$ is calculated for each of various combinations of t_1 and t_2 varied under a certain condition ($0 < t_2 - t_1 \leqq 36$ ms).

$$f(t_1, t_2) = \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right)^{2.5} \times (t_2 - t_1)$$

$$0 < t_2 \text{-} t_1 \leqq 36 ms$$

(1)

The performance value calculating section 12 further calculates an HIC value, using the above valuations $f(t_1, t_2)$. The HIC value is calculated using Eq (2) below.

HIC = Max($f(t_1, t_2)$)   (2)

In this equation, Max($f(t_1, t_2)$) means a maximum of $f(t_1,$

t_2) with change of t_1 and t_2. Here the valuation $f(t_1,$ t_2) is not calculated in the time domain where the acceleration $a(t)$ is not calculated. More precisely speaking, $\mathrm{Max}(f(t_1, t_2))$ thus means the maximum of valuation $f(t_1, t_2)$ with change of t_1 and t_2 in the time domain ($0 \leqq t \leqq t_e$) where the acceleration $a(t)$ is calculated last. Here, let us particularly define t_{1h} and t_{2h} as t_1 and t_2 presenting the maximum valuation $f(t_1, t_2)$, i.e., as t_1 and t_2 corresponding to the HIC value.

The HIC(d) is calculated using Eq (3) below, based on the foregoing HIC value.

$$\mathrm{HIC}(d) = 0.75446 \times \mathrm{HIC} + 166.4 \qquad (3)$$

Here the HIC(d) is qualitatively a value indicating the magnitude of impact exerted on Free Motion Headform, and the HIC(d) is desirably not more than 1000 in design of the pillar of a car.

The design variable determining section 14 sequentially sets numerous design variables for the calculation of acceleration $a(t)$ and HIC(d) in the performance value calculating section 12 and determines a specific design variable among numerous design variables, based on each of numerous performance values calculated by the performance value calculating section 12 and based on the certain evaluation criterion. More specifically, the design variable determining section

11

14 sets numerous combinations as to the rib thickness
of the pillar, outer wall thickness of the pillar, and
rib interval of the pillar for the calculation of
acceleration a(t) and HIC(d) in the performance value
calculating section 12 and determines a combination of
a rib thickness of the pillar, an outer wall thickness
of the pillar, and a rib interval of the pillar
presenting a minimum of HIC(d) calculated by the
performance value calculating section 12 under the thus
set combinations of the rib thickness of the pillar,
outer wall thickness of the pillar, and rib interval of
the pillar, as an optimal combination of rib thickness
of the pillar, outer wall thickness of the pillar, and
rib interval of the pillar.

The analysis end time determining section 16
determines an end time of the analysis in the
performance value calculating section 12 so that a
prescribed relation is met by an end time of a period
necessary for the calculation of performance value and
the end time of the above analysis. More specifically,
the analysis end time determining section 16 determines
the end time of the analysis so that a difference
between the end time of the period necessary for the
calculation of performance value and the end time of
the analysis becomes a predetermined, fixed value.
More specifically, the analysis end time determining

section 16 determines the analysis end time t_e so that the difference between the end time t_{2h} of the period necessary for the calculation of HIC(d) (i.e., the period necessary for the calculation of HIC value, which will also apply to the following), t_{1h} to t_{2h}, and the analysis end time t_e (the end time of the calculation of acceleration $a(t)$) becomes the predetermined, fixed value Δt, as shown in Fig. 2. Namely, the performance value calculating section 12 continues the calculation of acceleration $a(t)$ up to the analysis end time t_e determined as described above.

The determination procedures of the analysis end time t_e will be described in more detail, referring to Fig. 3A to Fig. 3C. First, let us consider a case where the calculation of acceleration $a(t)$ has been performed up to a time t_{e1}, as shown in Fig. 3A. If the HIC(d) is calculated assuming the time t_{e1} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will become equal to the above time t_{e1}, so that the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e cannot be the predetermined, fixed value Δt. Therefore, the time t_{e1} cannot be the analysis end time t_e, and the performance value calculating section 12 further continues the

13

calculation of acceleration a(t).

In the next place, as shown in Fig. 3B, there is illustrated the situation where the calculation of acceleration a(t) has been done further up to a time t_{e2}. If the HIC(d) is calculated assuming the time t_{e2} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will become smaller than the time t_{e2}, but the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e will be still smaller than the predetermined, fixed value Δt. Therefore, the time t_{e2} cannot be the analysis end time t_e and the performance value calculating section 12 further continues the calculation of acceleration a(t).

Then, as shown in Fig. 3C, there is illustrated the case where the calculation of acceleration a(t) has been conducted further up to a time t_{e3}. If the HIC(d) is calculated assuming the time t_{e3} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will be smaller by Δt than the above time t_{e3}, and the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e will become equal to the predetermined, fixed value Δt. Accordingly, the

14

analysis end time determining section 16 determines the time t_{e3} as the analysis end time t_e and the performance value calculating section 12 ends the calculation of acceleration a(t) at the point of the time t_{e3}.

5   The operation of the design variable optimization system according to the present embodiment will be described below and a design variable optimization method according to an embodiment of the present invention will also be described in connection

10   therewith. Fig. 4 is a flowchart showing the operation of the design variable optimization system 10 according to the present embodiment. In the design variable optimization system 10 of the present embodiment, first, the design variable determining section 14 sets a

15   design variable for the calculation of the acceleration a(t) and HIC(d) in the performance value calculating section 12 (S12). More specifically, the design variable determining section 14 sets a combination of a rib thickness of the pillar, an outer wall thickness of

20   the pillar, and a rib interval of the pillar for the calculation of the acceleration a(t) and HIC(d) in the performance value calculating section 12.

Then the performance value calculating section 12 performs the analysis on the design article in use of

25   the design variable thus set (S14). Here the analysis on the design article is a simulation concerning the

dynamic behavior of the design article. More specifically, the acceleration a(t) of Free Motion Headform at the time t is calculated in the situation where Free Motion Headform collides with the pillar of a car having the combination of the rib thickness of the pillar, outer wall thickness of the pillar, and rib interval of the pillar set by the design variable determining section 14. The acceleration a(t) is calculated by numerically solving a modeled collision phenomenon between the pillar of the car and Free Motion Headform by use of a differential equation (simulation).

The calculation of the acceleration a(t) by the performance value calculating section 12 is carried on up to the analysis end time t_e determined by the analysis end time determining section 16 (S16). Namely, the calculation of the acceleration a(t) by the performance value calculating section 12 is continued before arrival at the analysis end time t_e. Upon arrival at the analysis end time t_e on the other hand, the calculation of the acceleration a(t) by the performance value calculating section 12 is terminated.

The determination of the analysis end time t_e by the analysis end time determining section 16 is carried out as follows. Namely, as shown in Fig. 2, the analysis end time t_e is determined so that the

difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e (the calculation end time of the acceleration $a(t)$) becomes the predetermined, fixed

5   value Δt.

Describing in more detail, the analysis end time t_e is determined as follows. First, as shown in Fig. 3A, there is illustrated a situation where the calculation of the acceleration $a(t)$ has been done up

10   to the time t_{e1}. If the HIC(d) is calculated assuming the time t_{e1} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will become equal to the time t_{e1}, so that the difference between the end time t_{2h} of

15   the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e cannot be the predetermined, fixed value Δt. Accordingly, the time t_{e1} is not regarded as the analysis end time t_e.

Next, as shown in Fig. 3B, there is illustrated a

20   situation where the calculation of the acceleration $a(t)$ has been executed further up to the time t_{e2}. If the HIC(d) is calculated assuming the time t_{e2} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will

25   become smaller than the time t_{e2}, but the difference between the end time t_{2h} of the period t_{1h} to t_{2h}

17

necessary for the calculation of the HIC(d) and the analysis end time t_e will be still smaller than the predetermined, fixed value Δt. Therefore, the time t_{e2} is not regarded as the analysis end time t_e, either.

Then, as shown in Fig. 3C, there is illustrated a situation where the calculation of the acceleration $a(t)$ has conducted further up to the time t_{e3}. If the HIC(d) is calculated assuming the time t_{e3} as the analysis end time t_e, the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) will be smaller by Δt than the time t_{e3}, and the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e will become equal to the predetermined, fixed value Δt. Accordingly, the time t_{e3} is determined as the analysis end time t_e.

After the analysis end time t_e is determined, the performance value calculating section 12 calculates the HIC(d) for the set combination of the rib thickness of pillar, outer wall thickness of pillar, and rib interval of pillar (S18).

The steps of the setting of design variable (S12) to the calculation of HIC(d) (S18) are carried out for numerous design variables while giving various change to the design variable as the combination of rib thickness of pillar, outer wall thickness of pillar,

and rib interval of pillar.

After the steps of the setting of design variable (S12) to the calculation of HIC(d) (S18) are finished for all the design variables in the range to take into account (S20), the design variable determining section 14 determines as an optimal combination of the rib thickness of the pillar, the outer wall thickness of the pillar, and the rib interval of the pillar, a combination of rib thickness of the pillar, outer wall thickness of the pillar, and rib interval of pillar presenting a minimum of the HIC(d) calculated by the performance value calculating section 12 under the set combinations of rib thickness of the pillar, outer wall thickness of the pillar, and rib interval of the pillar (S22).

Next, the action and effect of the design variable optimization system according to the present embodiment will be described. The design variable optimization system 10 of the present embodiment determines the analysis end time t_e so that the prescribed relation is satisfied by the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e. Therefore, long and protracted analysis (the calculation of the acceleration $a(t)$) is prevented from being performed for the time unnecessary for the calculation of the

HIC(d), so that the analysis can be achieved with high efficiency. In consequence, the optimal design variable (the optimal combination of rib thickness of the pillar, outer wall thickness of the pillar, and rib interval of the pillar) can be determined within a short time.

The design variable optimization system 10 of the present embodiment determines the analysis end time t_e, particularly, so that the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e becomes the predetermined, fixed value Δt. Therefore, the analysis end time t_e can be readily determined. As a result, expediency is enhanced.

When the simulation concerning the dynamic behavior of the design article is necessitated on the occasion of determination of design variable, the simulation concerning the dynamic behavior is often accompanied by calculation of numerical solutions to a differential equation and often requires a long period of time. The design variable optimization system 10 of the present embodiment can efficiently curtail the time necessary for the determination of design variable, particularly, in the case wherein the simulation concerning the dynamic behavior of the design article is necessary on the occasion of determination of design

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variable as described above (e.g., when the pillar of car is designed).

The design variable optimization system 10 of the above embodiment was configured to determine the analysis end time t_e, particularly, so that the difference between the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) and the analysis end time t_e became the predetermined, fixed value Δt, but the analysis end time t_e may also be determined by other criteria. For example, the analysis end time t_e may be determined so that a ratio (t_{2h}/t_e) of the end time t_{2h} of the period t_{1h} to t_{2h} necessary for the calculation of the HIC(d) to the analysis end time t_e becomes a fixed value K (K > 1).

In the design variable optimization system 10 of the above embodiment the performance value calculating section 12 was configured to receive the analysis end time t_e directly from the analysis end time determining section 16 and terminate the calculation of the acceleration a(t) at the point of the analysis end time t_e, but the system may also be constructed like a design variable optimization system 20 as shown in Fig. 5. Namely, the design variable optimization system 20 is constructed in structure in which the design variable determining section 24 receives the analysis end time t_e determined by the analysis end time

determining section 26 and controls the analysis end

time t_e of the acceleration a(t) in the performance

value calculating section 22. The design variable

optimization system 20 is also able to determine the

5 optimal design variable (the optimal combination of rib

thickness of the pillar, outer wall thickness of the

pillar, and rib interval of the pillar) within a short

time as the aforementioned design variable optimization

system 10 was.

10 Although the design variable optimization system

10 of the above embodiment was described as the design

variable optimization system for designing the pillar

of a car, it is noted that the design variable

optimization systems according to the present invention

15 can be applied to determination of a specific design

variable among numerous design variables according to a

certain evaluation criterion, for any design article

that varies its performance with change of the design

variable.

20 The present invention can be applied to

determination of a specific design variable among

numerous design variables according to a certain

evaluation criterion, for any design article that

varies its performance with change of design variable,

25 e.g., for pillars of cars.

From the invention thus described, it will be

obvious that the embodiments of the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be

5   obvious to one skilled in the art are intended for inclusion within the scope of the following claims.